# SOIL EROSION MODELLING USING REMOTE SENSING AND GIS: A CASE STUDY OF JHIKHU KHOLA WATERSHED, NEPAL

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## ABSTRACT

In the process of soil erosion, nutrients rich top fertile soil is lost and it also causes environmental problems due to siltation of lakes, reservoirs and rivers. Inventory on soil loss and prediction of soil erosion hazard is vital for effective soil conservation planning of a watershed for sustainable development. Soil conservation is now a necessity in almost every country of the world under virtually every type of land use.

Information obtained using remotely sensing techniques can help decision makers to prepare resource map accurately in less time and cost. GIS, in other hand, helps in linking those maps with other information related to geographic location and helps modelling, analysing and solving complex problems. A case study describes and assesses soil erosion in a watershed belonging to the river Jhikhu Khola, in the middle mountain region of Nepal. Using ERDAS Imagine and ILWIS software, a landuse map was generated from satellite imagery of the study area.

For the estimation of Soil loss by Morgan approach, the various factor maps like kinetic energy of rainfall, Top soil rooting depth, percentage rainfall contributing to permanent interception and stream flow, Crop cover management factor, Ratio of actual to potential evapotranspiration, Soil moisture storage capacity were generated to get final output maps like Volume of overland flow; Rate of soil detachment by raindrop impact, Transport capacity of overland flow. Annual soil loss estimation is calculated by comparing two maps of soil detachment rate and transport capacity and taking the minimum value from them. Results provided by running a soil erosion model show that, rainfed agriculture is contributing maximum soil losses, 32.5 t/ha/yr. The lower soil losses are recorded under forest cover (0.01 - 0.4 t/ha/yr) and irrigated agricultural land (0.9 t/ha/yr). Average estimated annual soil loss of the study area is 12.6 t/ha.

## INTRODUCTION

Soil erosion control is vital if the increasing demand to feed the world is to be met. *The world's farmers are being faced with the daunting task of feeding some 93 million more people every year but with 24 billion fewer tons of top soil than the year before* (Lester Brown). Current rate of agricultural land degradation world-wide by soil erosion and other factors is leading to an irreversible loss in productivity on about six million ha of fertile land a year (Dudal, 1994). Resources like soil, water and forest can be managed effectively, collectively and simultaneously within this unit. Both food security and environmental issues should therefore be addressed within the contest of watershed management.

The consequence of soil erosion occur both on- and off-site (Morgan, 1986). On site effects are particularly important on agricultural land where the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure and the decline in organic matter and nutrient result in a reduction of cultivable soil depth and decline in soil fertility. Erosion also reduces available soil moisture, resulting in more drought prone conditions. The net effect is a loss of productivity which, at first; restricts what can be grown and results in increased expenditure on fertilizers to maintain yields but later, ultimately leads to land abandonment. Off-site problems result from sedimentation down stream, which reduces the capacity of the rivers, enhance the risk of flooding, blocks irrigation canals and shortens the design life of reservoirs. The on site costs of erosion are necessarily borne by the farmer although they may be passed on in part to community in terms of high food prices as yield decline or land goes out of production.

The prevention of soil erosion, which means reducing the rate of soil loss to approximately that which would occur under natural conditions, relies on selecting appropriate strategies for soil conservation and this, in turn, requires a through understanding of the processes of erosion. The factors, which influence the rate of the rate of erosion, are rainfall, runoff, soil, slope, plant cover and the presence or absence of conservation measures (Morgan, 1986).

Several parametric models have been developed to predict soil erosion at drainage basins, hill slopes and field levels. With a few exceptions, these models are based on soil type, landuse, landform, climatic and topographic information. Remote Sensing technique makes it possible to measure hydrologic parameters on spatial scales.
Scientific management of soil, water and vegetation resources on watershed basis is, therefore, very important to arrest erosion and rapid siltation in rivers, lakes and estuaries. It is, however, realized that due to financial and organizational constraints, it is not feasible to treat the entire watershed within a short time. Prioritization of watersheds on the basis of those sub-watersheds within a watershed which contribute maximum sediment yield obviously should determine our priority to evolve appropriate conservation management strategy so that maximum benefit can be derived out of any such money-time-effort making scheme.

Within any particular area there will be a considerable variation in erosion rates but if the rates are grouped into those related to natural vegetation, cultivated land and bare soil, each group follows a broadly similar pattern of similar variation.

Scientist found that, the dominant event, the one responsible for most work, was larger in magnitude than the most frequent event but was by no means extreme. Erosion is not a function of climate alone but depends on the frequency at which potentially erosive events coincide with ground conditions that favour the erosion. The most vulnerable time for erosion is the early part of the wet season when the rainfall is high but the vegetation has not grown sufficiently to protect the soil. Generally, the period between ploughing and the growth of the crop beyond the seedling stage contains an erosion risk if it coincides with heavy rainfall (Morgan, 1986).

Erosion and landuse change are very closely related. Rates of soil loss accelerate quickly to unacceptably high levels whenever land is misused. Erosion is a natural process but that its rate and spatial and temporal distribution depends on the interaction of physical and human circumstances.

## STUDY AREA

Jhikhu Khola watershed is one of the sub-watersheds of Sunkoshi river basin, which is one of the major tributary of Koshi River. Jhikhu Khola watershed lies about 45km east of Kathmandu between $27^o$ 33' and $27^o$ 42' N and $85^o$ 31' and $85^o$ 41' E with an altitude range from 860 to 2200masl. The watershed is located in middle-mountain of the Nepal.

The Jhikhu Khola watershed is leaf shaped. The maximum stretch of the watershed is from north-west to south east about 18km and its north-east to south west stretch is only about 10km. The general aspect of the watershed is south-east. Short and steep slopes are located in southern and northern sides. There are many pockets like valleys on the flanks, which make the watershed very heterogeneous. The watershed covers 111.4 sq. km.

Climate of the area is generally subtropical to temperate on high elevation. The watershed is subject to a monsoon climate with an extensive dry season from October to May. Summer commences from April to September and rainfall is received mostly from June to August (monsoon). The monsoon rainfall is closely related to altitude.

The watershed is one of the most intensively used Middle mountains areas of the Nepal. The main agricultural assets of farmers in this area are land and livestock (mainly milk production). The watershed is a main valley with a large flat valley bottom of alluvial origin, where the major landuse is irrigated agriculture (locally called *khet*). Over the last two decades, the dominant cropping pattern has shifted from rice, maize and wheat dominated production to one based on market economics, i.e. cash crops, which includes potatoes, tomatoes, pea, fruits and vegetables.

Physiographically the study area is a hilly terrain with steep side slope. Almost all agricultural fields are terraced (level and slopping). In slopes, trees are abundant around agricultural terraces, which give fuelwood, fodder and sometimes timber for household consumption.

Poverty and the ignorance are the main cause for land degradation. A lot of biomass is removed everyday from unprotected forest. Still, almost all inhabitants of the area are dependent on fuel wood for cooking and heating purpose. All of the problems commonly associated with population growth, agricultural intensification and deforestation in a marginal environment are present in this study area.

## DATA USED

For the present study, base map and the contour map were prepared from toposheets of survey department (2785 07 A/B/C/D). For preparing landuse map SPOT (HRVIR) data of 4th Jan 1999 was used. Soil and rainfall data were taken from year book of PARDYP, ICIMOD.

## METHODOLOGY

Firstly, toposheets were scanned and given respective geographic latitude and longitude projection to the corners. To get a single toposheet from four, they were mosaicked together. Output map is again reprojected into Transverse Mercator projection (as mentioned in toposheets).

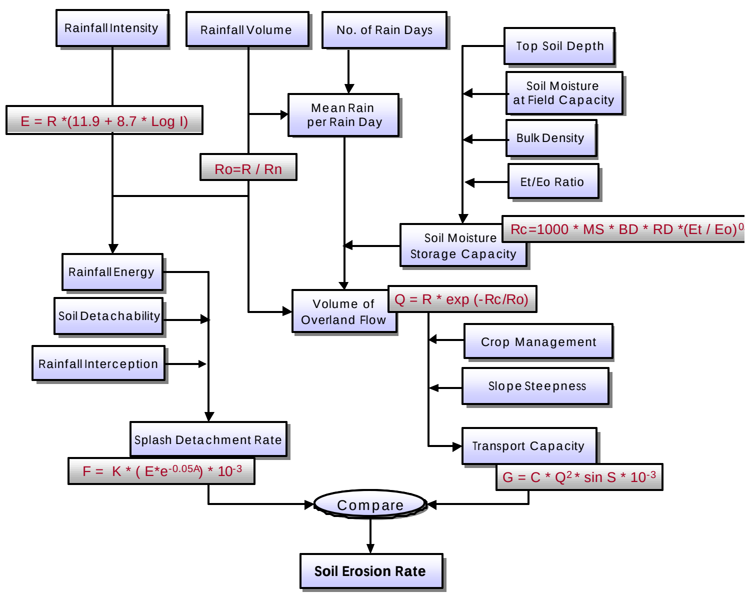


Figure 1: Flow Chart for the Morgan Method

Contour map and spot height point map were prepared by digitising contour (20m) lines and spot heights from the toposheets (mentioned above). Interpolation of these maps was done for getting final output map of DEM.

To rectify the spot image, a custom geometric correction model (in Erdas) was used. In this model, X and Y coordinates (Easting and Northing) are taken from toposheets and Z coordinates (height) are taken from DEM, which was produced from the contours and spot heights of the same toposheets. For this model, 50 uniformly distributed Ground Control Points (GCP) were taken and resampled by maximum likelihood method.

Clustering (unsupervised classification) and visual interpretation of satellite imagery of SPOT HRVIR (4th Jan 1999) was done for landuse mapping. Each cluster was classified into different landuse classes. Visual interpretation was done mainly in shadowed areas where clustering is not effective. For this purpose, frequent field visits and high resolution aerial photographs were used.

### Morgan Approach in Soil Erosion Modelling

Morgan, Morgan and Finney (1984) developed this model to predict annual soil loss from field-sized areas on hill slope. It considers soil erosion to result from detachment of soil particles by raindrop impact and the transport of soil particles by raindrop impact and the transport of those particles by overland flow. The processes of splash, transport and detachment by runoff are ignored. The model is a process based model which means that it runs in two phases one being water phase and the other being sediment phase.

**Water Phase:** Water phase mainly comprise of prediction of detachment by rain splash. It thus requires data related to rainfall such as the intensity of rainfall, number of rainy days, total rainfall.

Kinetic energy of rainfall, $E = R\ (11.9 + 8.7\log_{10}I)$, $J/m^2$ (1)

Where, R - Annual rainfall, mm
I - Intensity of erosive rain, mm/h

Volume of overland flow, $Q = R \exp(-R_c/R_0)$, mm
(2)

$$Rc = 1000 * MS * BD * RD *(Et / Eo)^{0.5} \quad (3)$$

Where, MS - Soil moisture content at field capacity (%, w/w).
BD - Bulk density of the topsoil layer (Mg/m).
RD - Topsoil rooting depth (m).
$E_t/E_0$ - Ratio of actual ($E_t$) to potential ($E_o$) evaporation.

$$R_o = R/R_n \quad (4)$$

Volume of overland flow, $Q = R \exp(-R_c/R_0)$, mm
(5)

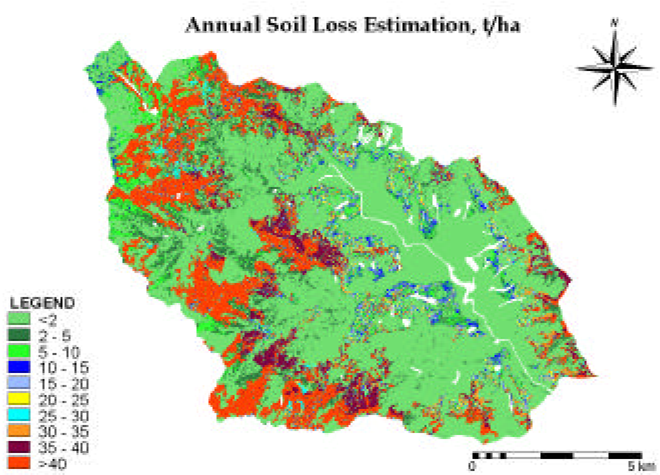


Figure 2: Soil Loss Estimation of the Study Area

**Sediment phase:** Sediment phase comprises of two predictive equations, one for the rate of splash detachment and the second for the transport capacity of overland flow. The sediment phase is thus simplification of the scheme described by Wischmeier and Meyer. The model also gives us an opportunity to incorporate the effects of soil conservation practices as there being changes in evapotranspiration, interception that will ultimately play a significant role in either increasing the volume of runoff, rate of detachment and transport capacity or vice versa.

The model has been proved to be sensitive to changes in annual rainfall and soil type. Thus good information in context of rainfall and soil is required for successful prediction (Morgan, Morgan and Finney 1984).

Rate of soil detachment by rain drop impact, $F = K(E_e^{-aA})b \times 10^{-3}$, Kg/m (6)

Where, K - Soil detachability index (g/J)
E - Kinetic energy of rainfall (J/m)
A - Percentage rainfall contributing to permanent interception and stem flow.
Values of exponents: a = 0.05, b = 1.0

Transport capacity of overland flow, $G = C * Q^d * \sin S * 10^{-3}$, Kg/m (7)

Where, C - Crop cover management factor
SinS - Steepness of the ground slope expressed as the slope angle.
Value of exponent, d = 2.0

Crop cover management values were assigned to the particular crop type in the land use map. Rasterised C map was than generated using attribute raster table. Slope map is derived from the DEM.

**RESULTS AND DISCUSSION**

More than half of watershed area falls under agriculture, with nearly 37% rainfed (*bari*) and 14% under irrigation (*khet, rice fields*). Only 1/3 area of the watershed is covered by forest (Dense - 10%, open – 12%, degraded – 11%). Rangeland which comprises grasslands and scrublands occupies about 15% of the total area.

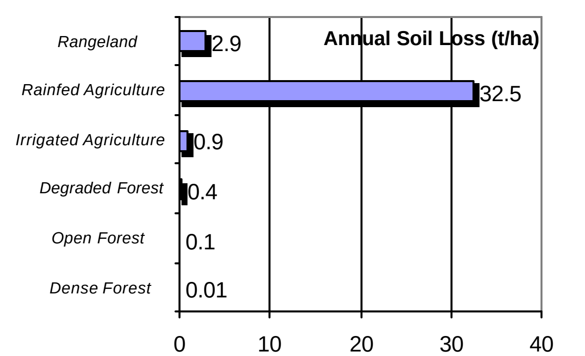


Figure 3: Soil Loss in Different Landuse

For the estimation of Soil loss by Morgan approach, the various factor maps like kinetic energy of rainfall, E; Top soil rooting depth, RD; percentage rainfall contributing to permanent interception and stream flow, A; Crop cover management factor, C; Ratio of actual to potential evapotranspiration, $E_t/E_o$; Soil moisture storage capacity, MS were generated to get final output maps like Volume of overland flow, Q; Rate of soil detachment by raindrop impact, F; Transport capacity of overland flow, G Annual soil loss estimation is calculated by comparing two maps of soil detachment rate and transport capacity and taking the minimum value from them.

Soil erosion intensity map is crossed with landuse map to get the amount of soil loss from different landuse classes. Average annual soil loss estimation is 12.6 t/ha. It was found that rainfed agriculture is contributing the highest annual soil loss (32.5 t/ha) and the forest showing the lowest (0.01 – 0.4t/ha). Irrigated agriculture and rangeland are contributing 0.9 and 2.3 t/ha respectively.

Rainfed agriculture are contributing more soil loss because most of them are located on sloppy lands of watershed (hence not irrigated) and only one crop per annum (rarely two) are cultivated in those fields. So, for several months, rainfed agriculture remains without vegetative protection from rainfall. In contrast, irrigated agriculture are mainly located in flat valley (0 – 10% slope). Since, they are irrigated, usually three crops (cereals, vegetables etc.) per annum are cultivated and those fields are rarely remains uncovered from vegetation, hence protected from rainfall impacts. Though, both agriculture lands are terraced rainfed are slopping terrace and irrigated are levelled one.

Slope map was generated from DEM and finally classified into various slope categories. Slope categories in percentage and soil losses for the watershed were plotted to find out the relationship between those two parameters. Soil loss increase as slope increases but after 50% slope, soil erosion tends to decrease due to presence of dense vegetation. Average NDVI lies between 0.21 – 0.24 for the slopes more than 50%, which lies between 0.18 – 0.21 for the slopes less than 50%.

Sliced NDVI map is crossed with the soil loss map to get relationship between those two parameters. From the histogram we can see, with the increase in vegetation cover, average soil loss dramatically decreases.

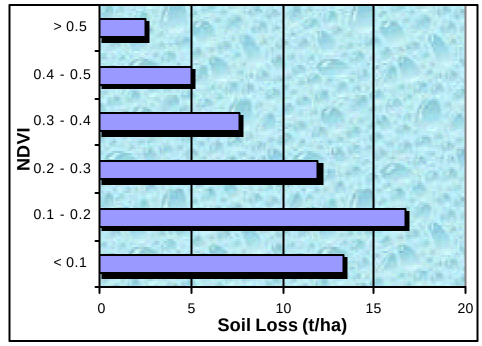


Figure 5: Relation between NDVI and Soil Loss

A risk of erosion exists on cultivated land from the time trees, bushes and grasses are removed. So, the conservation strategies are aimed at establishing and maintaining good ground cover. Forests provide excellent protection of the soil against erosion. They maintain high rates of evapotranspiration, interception and infiltration and therefore generate only small quantities of runoff. Low runoff rates and the protective role of the litter layer on the surface of the soil produce low erosion rates. Increases in erosion occur where the land is permanently or in the case of shifting cultivation, temporarily cleared for agriculture. First rains of monsoon are highly erosive. So, rapid establishment of crops is important particularly in those fields where erosion risk is high at and immediately after planting.

Experimental plots in the study area showed that during storms with low amounts of rainfall, water in agricultural areas infiltrates into the soil and stored. At rainfall volumes greater than 60mm, the infiltration/percolation rates in agriculture soils are too slow resulting in surface runoff (Nakarmi et al, 2000).

From the longer term data in the Nepal watersheds, erosion losses in rainfed agriculture are known to occur in the pre-monsoon season when the soils are barren and unprotected as a result of lack of vegetative cover. Up to 80% of the annual soil losses occur during this period. More than half of the annual sediments originate from degraded sites, which in spatial terms make up a relatively small portion of the watersheds in Nepal (Allen et al., 2000).

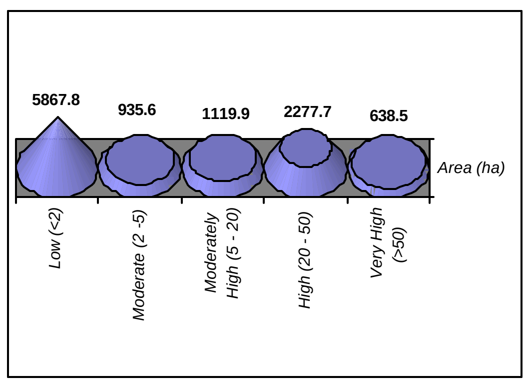


Figure 4: Area Falling Under Different Priority Classes

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